THURSDAY, SEPTEMBER 23, 1875

HELMHOLTZ ON TONE

On the Sensations of Tone as a Physiological Basis for the Theory of Music. By Hermann F. Helmholtz, M.D. Translated with the author's sanction by Alex. J. Ellis, F.R.S., &c. (London: Longmans and Co., 1875.)

IN the general advance of scientific knowledge which has taken place during the last half-century, the science of acoustics has hardly received its fair share of attention. Founded on principles originated by the ancients, and afterwards extended by Galileo, Newton, Taylor, Sauveur, Bernouilli, Euler, Smith, Young, and others, the first great and complete work on it was "Die Akustik," of Chladni, published in Germany in 1802, but which is chiefly known by its French translation.

It acquired a high and wide reputation, and it has ever since been a standard authority on the subject. Sir John Herschel's celebrated treatise on Sound in the "Encyclopædia Metropolitana," carried the theoretical views of the science much further, and so supplied what was deficient in Chladni's more practical work; but nothing of importance has been added to our knowledge of the science from Chladni's time till about fifteen years ago.

It was then known that one of the most eminent physicists and physiologists of Germany, Herr Helmholtz, Professor of Physiology at Heidelberg, had been devoting considerable attention to the science of acoustics, and, if we recollect aright, some of his discoveries were brought forward by himself in lectures at our Royal Institution. In 1863 appeared a work by him, entitled "Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik," the result of eight years' investigations in acoustical science. This work not only gave much new information on acoustical subjects generally, derived almost entirely from the author's own long-continued investigations; but it published new and most important discoveries as to the nature of musical sounds, and valuable reflections on the bearing of these discoveries on the theory of music generally. The work met with high and universal appreciation among those who could understand it; it went through three editions in Germany, and was translated into French, which gave it a much wider circulation. Helmholtz's book has been followed by two popular works in English, namely, "Lectures on Sound," by Prof. Tyndall (1867), and "Sound and Music," by Mr. Sedley Taylor (1873), the chief object of both being to expound Helmholtz's discoveries and doctrines to English readers. We have now, however, a translation into English of the entire work, as mentioned at the head of our article.

In attempting to give some idea of the book, it is necessary to premise that it treats of two distinct kinds of subjects, physical and musical. In addition to being a profound and practised physicist, the author has clearly devoted much attention to the study of music, both theoretically and practically, and he has endeavoured to apply his physical discoveries and theories to the elucidation of many points connected with the art which he has found obscure. We may therefore divide our notice into these two heads.

In regard to the physical part of the subject, Helmholtz's work owes its greatest interest and its greatest fame to the entirely new light he has thrown on the nature of musical sounds, and the complete way in which he has explained and accounted for phenomena in regard to them which were previously very obscure.

A little attention will lead anyone possessing an ordinarily susceptible ear to the perception that a musical sound has three properties, each of which may be subject to a wide range of variation. These are: (1) its *pitch*, or its degree of acuteness or gravity in the musical scale; (2) its *strength*, or degree of loudness or softness; (3) the *quality*, or character of tone.

The question then naturally arises to what physical circumstances these three peculiarities are due. In regard to the two first there has been no great difficulty. It has been long known that the *pitch* of a musical sound depends on the rapidity of the vibrations which cause it, for according as the vibrations succeed each other more or less rapidly, the note produces sounds to us more acute or more grave, or, in other words, its pitch is higher or lower.

The *strength*, or degree of loudness or softness of a musical sound, has been also known to depend on the *amplitude* or extent of the vibrations, a larger amplitude giving a louder sound, and *vice versâ*.

The third property of musical sounds is their *quality* or peculiar character of tone. A violin, for example, gives a tone of a different quality from that of a clarionet, an oboe, a flute, or a trumpet, which all again differ from each other. The varieties of quality of tone that may be obtained are almost infinite; we not only possess an immense variety of musical instruments and means of producing musical sounds, all which have their individual qualities of tone, but even on the same instrument the same note may often be given several different varieties of character, independent of the mere loudness or softness. And that these infinite varieties are really objective physical differences, and not merely subjective or ideal, is proved by the facility with which educated ears can identify and distinguish between them, even sometimes to the minutest shades of difference. The stringed tribe of instruments, and still more the human voice, furnish ample examples of this.

The tone of a particular violin, or of a particular violin player, can be identified by a connoisseur among a hundred, and we all know that the varieties of quality of the human voice, even in the same register, are as easily recognised by the ear as the varieties of physiognomy are by the eye. And even in the same voice, the numerous varieties of vowel sounds producible are, when examined carefully, only varieties in quality of tone.

The nature of this property of sounds has hitherto been very obscure. Chladni, the great expounder of acoustical science in the early part of this century, says:—"Every real musical sound is capable of different modifications, whose nature is as yet entirely unknown, but which probably consist of some mixture of what is simply noise." He then explains at some length that this may arise either from peculiarities in the structure of the sounding body as regards material, &c., or from the

Y

nature of the body with which it is struck or rubbed, to produce the sound. He further adds the suggestion that such irregularities may be due to irregular tremblings of the smaller parts of elastic bodies.

Sir John Herschel ("Encyclopædia Metropolitana"), speaking of musical sounds, says · "Of their quality and the molecular agitation on which they depend, we know too little to subject them to any distinct theoretical discussion."

To put the problem clearly, suppose we have two musical sounds of the same pitch and the same degree of loudness, but of different qualities. To what physical cause is the difference in quality due? We know that the rapidity and the amplitude of the vibrations is the same in both cases; what other element of variation can enter into the phenomenon? Helmholtz is the first who has given a complete answer to the question.

It very seldom happens that a musical sound consists of one simple note; it is generally a compound of many notes combined together. To illustrate this by a simple example, suppose a stretched string, as a violin string or pianoforte wire, sounds any particular note. This note, which is called the fundamental one, will be due to the vibrations of the string as a *whole*, and if we could prevent any other kind of vibration this sound would be a simple one. But the string has a natural tendency (for reasons too recondite to enter upon here) to take upon itself other partial vibrations, and thereby to complicate the effect produced. It will divide itself spontaneously into two, three, four, five, six, or more aliquot parts, and each of these parts will set up an independent vibration of its own, giving a new note corresponding to its length. All these will sound together, and thus by the vibration of the string we get not only the fundamental note (which is usually the loudest and most prominent), but its octave, its twelfth, its double octave, its seventeenth, nineteenth, and so on, all heard in addition, and giving a sound which is a compound of them all. All the additional notes above the fundamental have been usually called in England *harmonics*; Helmholtz calls them *overtones* (obertöne).

We have given a string as a simple example of the mode of generation of a compound sound, but such sounds are produced in many different ways. A compound sound, so far as its effect on the ear is concerned, is due to a particular form of air-wave, produced in the instance given by the superposition of different sets of vibrations of the sounding body; and such a form of wave may be equally well produced by other means, such as a reed; or it may originate in the air itself, as in a flute. In every case where a given fundamental note is found, there is the same tendency for it to be accompanied by subsidiary fractional vibrations, producing corresponding overtones.

The phenomenon of compound sounds, as found by harmonics or overtones accompanying fundamental sounds, has been long known. It was mentioned by Mersenne as early as 1636, and has since been noticed by Bernouilli, Young, Rameau, Chladni, Sir John Herschel, Woolhouse, and others; but there is great difficulty in getting practical musicians, who have not been accustomed to considerations of this nature, to admit that what, judging by the practical impression on the ear, seems only a simple and single note, can really be one compounded of a great many sounds differing much in pitch, and some absolutely discordant. Helmholtz endeavours to combat this prejudice. He shows by several analogous physical and physiological examples that the senses are apt, in the presence of prominent facts, to ignore others which may be less prominent but equally real; and he reasons that as the fundamental note is almost always stronger than any of the others, the ear is inclined to refer the whole combination to that one note, and refuses to take the trouble of separating and identifying the various elements of the sound.

An example of artificial compound sounds, purposely made, is furnished by a large organ. The pipes from which its sounds arise are in themselves but weak, and no multiplication of them would give tones of great power. Hence the long experience of organ builders has led them to form compound sounds by adding to each note pipes speaking its octave, twelfth, fifteenth, and other "overtones," the effect of which is, as is well known, to produce sounds of almost powerful and penetrating quality. Yet, if these overtones are well proportioned, they give, to an ordinary hearer, only the impression of one single loud sound.

By a little practice the ear may be educated to distinguish and separate the various notes which make up a compound sound, and when the habit of doing this is acquired, the illusion disappears. But that no proof may be wanting of this important principle, Helmholtz has contrived mechanical means by which any sound may be analysed, like a ray of light or a chemical compound, and its component parts exhibited separately. He has contrived certain instruments called resonators, each of which will, like a chemical reagent, test the presence of a particular overtone, and by submitting these in succession to the vibrating influence of the compound tone, they at once show whether the sounds they are tuned to are present or absent therein.

We have dwelt at some length on this phenomenon of the compound nature of musical sounds, because it is in reality the great fact which underlies the whole of Helmholtz's researches in this volume, and he himself has accordingly taken great pains to demonstrate and explain it, knowing that, although not a new discovery, it was yet far from being generally acknowledged. Indeed, we consider the establishment of this fact, so difficult of acceptation by practical musicians, and yet so simple and obvious when explained, is one of the most useful and important features of that portion of the complete work now under review. This establishment and explanation he afterwards uses as the basis for most of his researches, namely, the compound nature of musical sounds.

Such sounds, we have shown, consist, in almost all cases, not of a simple vibration, but of a number of vibrations of different velocities, superposed upon a fundamental one. The whole thus form a compound vibration which, though it produces on the inexperienced ear the effect of a single note, is really, when analysed, a compound of this note with a number of "overtones" harmonically related to it.

Among the many novel uses Helmholtz makes of this fact, the most important, physically, is the way in which he deduces from it the explanation of the third property we have mentioned of musical sounds, namely, their quality or character of tone.

Chladni was perfectly aware of the complex and varied nature of the vibrations producing musical sounds, but he does not seem to have attached any importance to them in this respect; for he says (p. 48, ed. 1830): "Die Verschiedenheit der Schwingungsarten trägt meistens nur wenig zu einer verschiedenen Wirkung des Klanges bei."

Sir John Herschel (Encycl. Metrop.) appears to have doubted Chladni's assertion, for he hints clearly at the probable influence on the quality of the sound, of the *form of the air-wave* (which is only the result of the complex vibration); and we may probably consider this to be the first hint on record pointing to Helmholtz's discovery.

Mr. Woolhouse, in an admirable little "Essay on Musical Intervals, Harmonics, &c.," 1835, goes further. He says (p. 77), speaking of the complex vibrations of a string: "The various combinations of these different modes of vibration must have a considerable influence on the musical quality and expression of the musical sound," which is a still nearer anticipation of the later doctrine.

Still, however, these anticipations were only guesses; it was reserved for Helmholtz to put the matter in the shape of a scientifically demonstrated fact. He has shown, by the most elaborate and conclusive investigations, that the *quality of a musical tone depends chiefly on the number and on the comparative strength of the various harmonical notes of which the tone is compounded.*

The overtones accompanying a fundamental note may be present in greater or less number, and they may vary considerably in comparative loudness or softness, and it is on the combination of these sources of variation that the quality of the tone will depend—or, to put the explanation in another and more scientific shape; as the *pitch* of a sound depends on the length or the frequency of recurrence of the air-wave, and the *loudness* on the degree of disturbance of the particles of the air therein; the *quality* of tone depends on what is called its internal *form*, or on the varieties of arrangement of expansion and compression of the air contained within one complete periodic cycle of oscillation.

Some modification in effect is often produced by a sound being accompanied by unmusical noises, such as the escaping of imperfectly used wind in a pipe, the unskilful scratching of the bow on a violin, the beating of reeds, and so on; but these are rather impurities than varieties of tone, and may be excluded from consideration.

There are very few natural sounds which are entirely simple, consisting of the fundamental note only. They are best produced artificially by means of the "resonators." The nearest approach to them may be found in the larger stopped wood pipes of an organ, an old-fashioned (not a modern) flute, and a tuning-fork after the sharp ring has subsided. The vocal sound of the Italian U (our *oo*) is also nearly a simple one. These examples will give the idea that simple tones are soft, dull, and entirely devoid of what is called brilliancy.

The addition of overtones gives this brilliancy and at the same time adds life, richness, and variety. It is to them that we owe entirely the agreeableness and pleasurable effect of musical tones. In proportion as the higher overtones predominate, so will the sound be bright and sparkling, or if in great predominance it will become metallic, thin, and wiry. If, on the other hand, the upper tones are weakened and the lower strengthened, the tone becomes more full, rich, and mellow. All the qualities of tone most esteemed and most useful in music are rich in overtones.

Helmholtz gives many examples of musical sounds of different character, which have been analysed according to his method. The tones produced from strings are peculiarly adapted to this purpose, because the vibrations so produced admit not only of mathematical calculation, but of ocular observation, and so give direct means of comparing the new theory with the facts, the result in all cases being most satisfactory and conclusive. The overtones in strings depend largely on the kind of impulse and the place where it is applied. In an ordinary piano the first six overtones are all audible, the three first strong, the fifth and sixth weaker, but still clear. The seventh and ninth, which are inharmonious, are excluded by striking the string in a peculiar place which does not admit of their generation. To prove the dependence of the quality on the strength of the overtones, Helmholtz has calculated mathematically what the strength of the first six overtones ought to be when produced with hammers of different degrees of hardness, and finds they should be as follows:—

	1.	2.	3.	4.	5.	6.
With a very hard hammer	100	325	500	500	325	100
With a medium hammer	100	249	243	119	26	1
With a very soft hammer	100	100	9	2	1	0

Now, as everybody who knows anything about pianofortes is aware that the tone is full and rich with a soft hammer, and hard and jangling with a hard one, it will be seen how admirably the mathematical results correspond with the actual ones, and how both confirm the theory.

Again, it is easily shown, both mathematically and practically, that thin wires will vibrate in short lengths much more easily than thicker and stiffer ones, and will therefore be more liable to produce the higher overtones, and hence the well-known metallic jangling of thin wires. This is the scientific explanation of the improved tone from the use of thicker wires in modern pianos, inasmuch as they admit of a more powerful blow without the production of the high and unfavourable overtones that would result from such a powerful impulse on a thin string.

The peculiar tones of the violin tribe, wind instruments, wood and brass, organ-pipes of various kinds, and so on, are all satisfactorily investigated in this way.

Helmholtz devotes much attention to the phenomena of vowel sounds, which had been already investigated by Willis and Wheatstone. He has completed their investigations by bringing the vowel sounds within his theory, and his elegant discussion of the subject, and the important results he obtains, are among the best features of his book.

All the above results we have mentioned have depended on the *analysis* of musical sounds. But the author has not stopped here. In chemistry, when a discovery has been made of the constitution of a compound body, by analysing it into its constituent elements, the efforts of the chemist are naturally turned to the converse process of proving the same proposition by synthesis, or by combining the single elements and showing that they will produce the compound. This proof has not been wanting in the present case, for Helmholtz has succeeded in combining simple sounds together in such a way as to produce imitations not only of vocal sounds, but of many other peculiar qualities of tone; not perfectly, from the extreme difficulty of imitating exactly all the minute shades of difference that enter into the combination, but still with enough success to demonstrate the general argument.

We have given especial prominence to Helmholtz's discoveries on the nature of musical sounds, because this is in reality the great feature of his work, by which it first acquired its fame, and by which his name will hereafter be honoured. But the physical part of the book contains much beside this that is important and interesting. His explanations on the general phenomena of acoustics are most lucid, and often very original; and his descriptions of the mechanism and action of the organs of hearing, coming from one of the highest authorities in physiology, are exceedingly instructive and valuable.

In Part II. the author enters into an investigation of what are called *beats*—a subject which has been heretofore very obscure—and also of other acoustical phenomena called "combination tones," which, though known since the time of Tartini, have not been thoroughly understood till Helmholtz gave their explanation. Into these matters we have not, however, space to follow the author: those who are interested in them can refer to the book for themselves.

Before we leave the physical part of the work it will be only just to testify to the excellence of the translation. Mr. Ellis is so well known as a philologist and a man of science, that his competence to deal with the work in a literary and scientific point of view requires no comment, and English readers may be satisfied that in this translation they have the original faithfully put before them. His work has evidently been a labour of love, and he deserves the highest credit for the trouble he has taken over it.

At the same time all men are fallible, and when a great authority condescends to do a work that could hardly be expected from him, we must not be unprepared for some little waywardness on his part, and there are a few things which we would rather have seen otherwise done. The title of the book is unfortunate; for, although no doubt "The Sensations of Tone" is a correct translation of "Tonempfindungen," yet to many English ears it will, we fear, sound strange and unintelligible from the fact that we are hardly accustomed in our language to understand the word "tone" in the sense here intended. The English title certainly does not give to the English reader anything like the same idea as the original title, "Die Lehre von den Tonempfindungen," does to an educated German. The strict rendering of a German phrase does not always correctly represent the original; for example, in speaking of the clever little tract of Hauslick, "Ueber das Musickalisch Schöne," Mr. Ellis translates it, "On the musically beautiful," whereas, as every reader of the tract well knows, the more appropriate expression in English would be "On the beautiful in music."

But the chief fault we have to find in the translation is the rendering of a term which of all others is the most important in the whole work, and in which the translator has, we conceive, taken a liberty not altogether justifiable. Helmholtz, in describing the compound nature of musical sounds, has called all the sounds above the fundamental one by the name of "obertöne," a word exceedingly appropriate, useful, and expressive, inasmuch as it at once defines and includes all these sounds in one appellation. Prof. Tyndall, in his *résumé* of Helmholtz's discoveries, has most naturally and with great propriety translated this term by the word "overtones." It exactly expresses the German in the simplest way, and it is as perfectly admissible into English as "overcoat" or "overseer."

Unluckily, Mr. Ellis is either too proud to adopt this word or has taken otherwise a dislike to it; for, on the ground that he does not consider it good English, he substitutes for it the expression "upper partial tones." This is not only clumsy and roundabout, but it is imperfect and wrong, inasmuch as it does not include, as the original expression does, the *whole* of the sounds above the fundamental, and gives no means of distinguishing higher overtones from the lower ones. As these overtones play such an exceedingly important part in Helmholtz's work, we cannot but consider, with all respect to Mr. Ellis, this rendering a blot on the translation which we very much regret.

We must reserve our notice of the musical portion of Helmholtz's work till a future opportunity.

OUR BOOK SHELF

Guide to the Geology of London and the Neighbourhood (Geological Survey of England and Wales). By William Whitaker, B.A., F.G.S. (London: Messrs. Longmans and Co., 1875.)

It is a matter of great satisfaction to geologists that the Geological Survey are again giving to the public some of the accumulated stores of information of which they are necessarily possessed, by resuming the series of large and complete memoirs which had been in abeyance for many years before the publication of "Whitaker's Geology of the London Basin," Part I., in 1872—a series now so well continued by the works of Judd and Topley. These, however, are comparatively expensive, and enter into minute details, so that although the whole of the information contained in the small book under notice has already been given at greater length in Mr. Whitaker's work mentioned above, or will be in a similar promised publication on the "Drifts of the London Basin," it will be of great use to a large number of persons who would not care for a more detailed description. A special Geological Map of London and its Environs, with all the Drift beds indicated, has lately been published, and for the last two years the Geological Model of London on a six-inch scale has been the admiration of all visitors to the Jermyn Street Museum: the pamphlet now before us is designed as a handbook to these. It commences with a description of the construction of the model, a matter of no small difficulty, considering the accuracy of the representation. The description of the various formations which enter into the London area, with their resulting features and scenery, though necessarily short, contains the cream of all the known facts, and what is better still, the reasons for all the not self-obvious determinations of the age and